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Inverted Pyramid-Shaped Plugs for Closing Abandoned Mine Shafts—Galena, KS, Demonstration Project

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CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	lb	pound
ft^2	square foot	yd^3	cubic yard
in	inch		

INVERTED PYRAMID-SHAPED PLUGS FOR CLOSING ABANDONED MINE SHAFTS—GALENA, KS, DEMONSTRATION PROJECT

By W. M. Dressel[1] and John S. Volosin[2]

ABSTRACT

This Bureau of Mines report describes a shaft closure demonstration project in which 11 inverted pyramid-shaped plugs were used to plug abandoned open mine shafts in Galena, KS. The inverted pyramid-shaped forms, fabricated from steelplate, were designed so that the inverted base would be larger, by 4 ft on a side, than the approximate size of the shaft opening at the surface residuum-solid rock interface.

After the surface openings of the shafts were trimmed with a backhoe, the steel forms, complete with reinforcing, were lowered into the openings and filled with concrete; the remaining portions of the openings above the plugs were backfilled to slightly above the surrounding surface level with waste rock and soil.

Location and elevation monuments were installed for long-term evaluation of the success of the project.

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INTRODUCTION

The Bureau of Mines operated a shaft closure demonstration project in Galena, KS, in which 11 inverted pyramid-shaped plugs were installed in abandoned open mine shafts. The primary purpose of the project, which was part of the Bureau's Conservation and Development Program for conserving land resources, was to provide alternative methods for closing some of the hundreds of open shafts in the area.

The Galena field is in the Tri-State zinc-lead belt district of Kansas Missouri-Oklahoma, which was one of the largest zinc-lead mining districts in the country. The district produced over 11 million tons of zinc and 2.8 million tons of lead during its 122 years of operation.

Mining began in the Tri-State district in 1848 with the discovery of lead ores in Joplin, MO. Increased mining activity developed in the 1870's, coincident with the extension of the railroad into the area and the development of new milling and smelting techniques for zinc. By 1875, the Joplin field became the leading zinc producer in the Nation. Mining moved westward with the discovery of the Galena, KS, field in 1877; the Peoria, OK, field in 1891, and the Commerce, OK, field in 1905.

Mining continued in the Missouri portion of the district until 1957 and in the Kansas-Oklahoma portion until 1970.

Early mining leases were generally small with many leases being only 100 or 200 ft square (1-4).[3] The ore was mined by small crews of men using handtools and simple hoisting devices. Exploration was done by sinking a shaft, generally 50 to 100 ft deep, until ore was found and then drifting outward (5). If drifts reached 300 ft in length or if ventilation became difficult, additional shafts were sunk. If ore was not encountered, the miner moved to new ground and sank another shaft. In 1892, Henrich (6) reported that diamond drills were being used for prospecting deeper than 100 ft. The churn drill replaced shaft sinking as the principal exploration tool about 1900 (3, 7).

The use of shafts as a means of exploration and the small lease and sublease mining plots resulted in a high density of mining shafts in the area. Many of these shafts remain open. They are constant safety and environmental hazards and limit the uses for the land.

In preparing a series of reports for the Bureau, the State Geological Surveys of Kansas, Missouri, and Oklahoma located over 1,400 abandoned open mine shafts in the Tri-State district (8-10). In the Galena, KS, field alone, 377 open shafts were located within or adjacent to the city limits of Galena. All but 11 of these shafts showed surface enlargement because of cribbing removal or failure.

Backfilling is a common method for filling shafts and is quite successful if done properly with graded material free of degradable trash and in a manner that avoids temporary bridging. Wood planking has been used with varying degrees of success but eventually decays, resulting in an unsafe closure. Although concrete caps have been successful in some instances, there are examples of failed concrete caps in the Galena area where the caps were improperly reinforced or where undercutting around the shaft caused the cap to tip on end, thus creating a hazard from an open shaft.

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[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

In the Picher field, at least one company successfully used concrete cubes to close shafts when abandoning the field. The cubes, which were 6-1/2 ft on a side, were constructed on the surface next to the shaft and then rolled into the opening and wedged into place by undercutting and blasting.

This report describes a method using an inverted pyramid-shaped plug that would be easy to install and would seal itself into the shaft. The weight would be distributed to the edges and sides of the shaft.

SELECTION OF SHAFT SITES

Galena was picked as a site for demonstrating methods for closing abandoned shafts because over 350 open shafts were readily accessible in a populated area. Before a location was selected for the demonstration, the Bureau contacted the Galena city government for its view as to which areas within the city limits were in the most need of shaft plugging. From the locations the city officials listed, the Bureau selected a site in NE1/4SW1/4 sec. 14, T 34 S, R 25 E at the west end of Front, First, and Second Streets. Virtually all of the open mine shafts in Galena are on privately owned land. A search of the county land records was made to determine the ownership of the lands, and the owners were contacted to obtain grants of easement that would permit the Bureau to carry on the demonstration project. Figure 1 shows location of the site and the location of the shafts closed during the demonstration; the breaks in the shaft numbering sequence resulted from changes in the original closure plan, brought about in one case because considerable construction debris had been dumped in the opening and in other cases because the locations were out of the area covered under the grants of easement.

Four of the open shafts selected for plugging are shown in figures 2 through 5. Contract 50/34005 was let to Goodson and Associates, Inc., Denver, CO, in 1982 to obtain the shaft dimensions, assess the conditions of shaft side walls, and obtain an estimated contact between overburden and solid rock. These measurements were used in preparing bid specifications for the plug installations reported herein. Eleven shafts were plugged, two were capped, and one was backfilled during the demonstration.

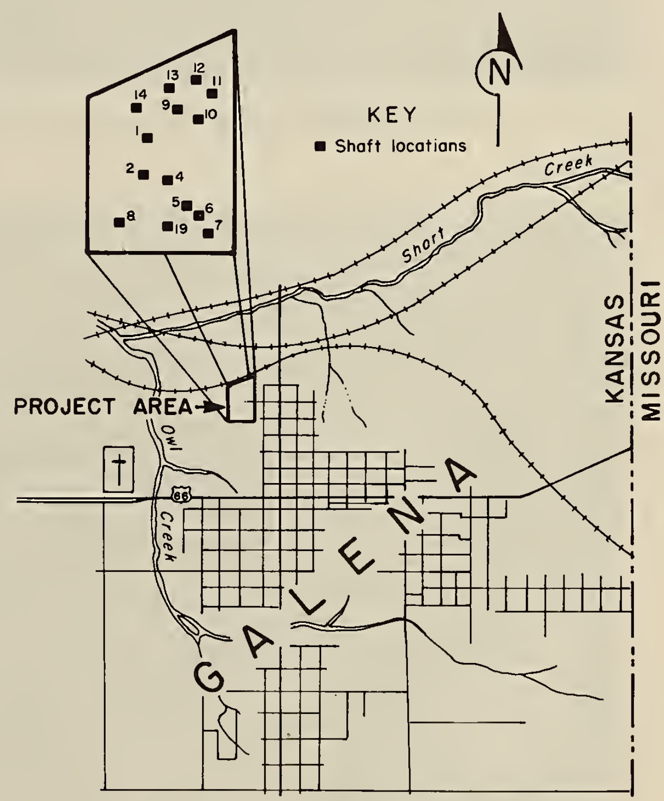

FIGURE 1. - Project site location.

FIGURE 2. - Typical open shaft with timber still in place.

FIGURE 3. - Typical open shaft with enlarged surface opening.

FIGURE 4. - Typical shaft showing rotted timber and washout along timbers.

FIGURE 5. - Typical open shaft showing circular outline in slumping residuum.

DESIGN OF PLUG

Pyramidal-shaped plugs designed for the project consisted of prefabricated steel forms with installed reinforcing, which were lowered into the prepared shaft opening and filled with concrete.

The shafts were roughly square and ranged in size from 4 to 8 ft. The forms for the plugs were designed so that the tops of the plugs were approximately 4 ft larger on a side than the size of the shaft opening. The shape of the form was that of an inverted 45° pyramid. A sketch of an installed plug is shown in figure 6. Of the 11 forms required for the demonstration, 3 were 8 by 8 ft, 6 were 10 by 10 ft, and 2 were 12 by 12 ft. The 8- by 8-ft and the 10- by 10-ft forms were constructed of 3/16-in hot-rolled low-carbon steelplate welded at the seams. The 12- by 12-ft forms were constructed of 1/4-in hot rolled low-carbon steel. The external edges of the seams were reinforced by the addition of a fabricated angle, approximately 3 in on an edge, welded to the seam. This reinforced edge proved very beneficial since much of the weight of the plug rested on the corners before seating.

A horizontal reinforcing rod grid was placed 1 ft from the top in the 8-ft-square pyramid forms, 1.25 ft from the top in the 10-ft forms, and 1.5 ft from the top in the 12-ft forms. A 12-in grid spacing was used for both east-west and north-south positions (fig. 7). Grade 60, No. 7 reinforcing bars were used in each instance.

In the 10-ft form, two S4 I-beams with 0.326-in web thickness approximately 6 ft long were welded to a 1/4-in footplate which was welded to the sides of the form. The beams were arranged parallel to each other and spaced approximately equidistant from the parallel side walls and from each other (fig 8).

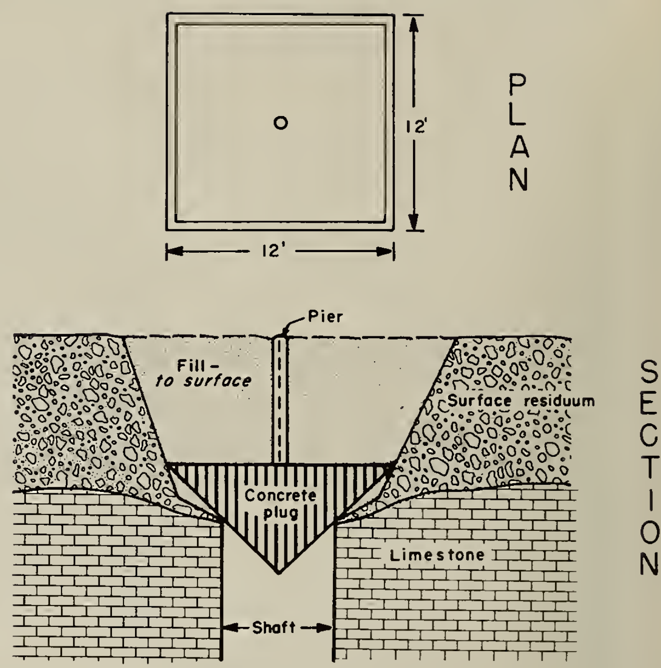

FIGURE 6. - Installed plug.

To brace the side walls of the 12-ft form, two S4 I-beams, approximately 8 ft long with a 0.326-in web thickness, were welded to the form at right angles to each other. The ends of these beams were welded to a 1/2-in plate at least 1 ft square, which in turn was welded to a 1/2-in plate at least 1 ft sq which, in turn, was welded to the inside of the form approximately 2 ft from the top (fig. 9).

Vertical reinforcing bars were placed 6 in from each of the sloping sides of the pyramidal form. They were spaced 1 ft apart at the top of the form and tapered down to a few inches near the bottom. The top end of the rebars extended to within 6 in of the top of the form. A spacer was welded approximately 1 ft from the tip of each form to hold the rods 6 in from the side walls (fig. 9).

Material requirements per plug are tabulated in table 1.

TABLE 1. - Material requirements per plug

	Approximate shaft size		
	4 ft	6 ft	8 ft
Pyramid form size...........ft..	8×8×4	10×10×5	12×12×6
Metal preform,.............ft^2..	[1]90.51	[1]141.2	[2]203.6
Weight of metal preform.....lb..	693	1,083	2,079
Estimated rebars per shaft:			
Linear ft....................	327	495	698
Weight...................lb..	660	1,020	1,420
I-beam:			
Length...................ft..	0	12	16
Weight...................lb..	0	89	118
Edge angle:			
Length...................ft..	27.7	34.6	41.6
Weight...................lb..	260	325	391
Total weight of steel.......lb..	1,613	2,517	4,008
Concrete.................yd^3..	3.2	6.2	10.7

[1]3/16-in cold-rolled, low-carbon steel plate.
[2]1/4-in cold-rolled, low-carbon steel plate.

FIGURE 7. - 8-ft form showing reinforcing grid.

FIGURE 8. - 10-ft form showing I-beam position and reinforcing grid.

FIGURE 9. - 12-ft form showing I-beams and position of horizontal and vertical reinforcing bars.

INSTALLATION OF PLUGS

The contractor, using a backhoe, trimmed sufficient material from around the surface of each open shaft to provide a reasonably level contact between the surface residuum and the bedrock. In several cases rock ledges or boulders needed to be trimmed to provide a suitable bearing surface for setting the forms. Trimming was done with a jackhammer bit fitted to the backhoe.

The prefabricated forms were delivered to the site on a flatbed trailer and were unloaded from the truck and placed directly in the hole using a 17-ton crane (fig. 10). In several cases, additional sidewall trimming using the backhoe and/or jackhammer was required to obtain a level position for the forms.

A 4-in pipe was positioned in the center of each plug and was long enough to extend above the surface level of the ground after backfilling. These pipes were designed to remain as reference markers for followup evaluation.

Class A concrete was delivered to the site from a local batch plant and poured into the forms. The 8-ft forms each required 3.2 yd^3 of concrete, the 10-ft forms 6.2 yd^3, and the 12-ft forms 10.7 yd^3.

After the first three plugs were placed, it was noted that since the mine openings were only roughly square, there were noticeable gaps between the form and the sidewalls at some places (fig. 11). In these areas, reinforcing bars were positioned over the edge of the form and extended to the side of the prepared opening. This was covered with a 2-ft width of expanded metal, and 4 in of concrete was poured on this expanded metal (fig. 12). Figure 13 shows the same hole after the completion of the edge pour.

FIGURE 10. - Lowering form into opening.

FIGURE 11. - Form filled with concrete showing space between form and shaft wall.

FIGURE 12. - Poured plug with expanded metal edging resting on reinforcing bars.

FIGURE 13. - New concrete poured on expanded metal surrounding plug.

Before pouring concrete in the last eight forms, steel reinforcing rod was bent and fastened to the installed horizontal reinforcing grid and extended in spider-leg fashion several feet over the edge of the form. The 2-ft-wide expanded metal was positioned over these reinforcing rods, and concrete was poured over this when the form was filled. Figure 14 shows the positioning of the spider legs and expanded metal.

An additional 1 to 1-1/2 yd^3 of concrete was required for each shaft because of these modifications.

In the installation of one 12-ft and one 10-ft plug, the center reinforcing bars were left unwelded to the sides of the form to allow the form to bulge along the edges to better fill the gaps. This appeared to be an effective measure.

BACKFILL

After a concrete curing period of at least 7 days, the holes were backfilled with waste rock available near the shafts. The backfill at each site was mounded so that the center of the fill was approximately 2 ft above the surrounding ground surface. The 4-in pipe extending from the center of each plug was trimmed so that it extended 6 in above the fill; it was filled with concrete and will remain as a marker for evaluation purposes. These markers have been located, and elevations of their tops have been determined.

FIGURE 14. - 10-ft form showing spider-leg reinforcing over edge of form to support the expanded metal.

INSTALLATION OF SLAB CAPS

In some instances, solid rock exposed at the surface was competent enough so that there was virtually no cratering or shaft enlargement at the surface. In these cases, it was found expedient to trim away loose surface rock and install reinforced concrete slabs. Two mine openings, approximately 4.5 by 4.5 ft, were closed by this method during the completion of the project.

The slabs were designed to extend approximately 5 ft over each edge of the open mine shafts. A reinforcing grid of No. 7 rebars spaced 1 ft apart at the edges, 1/2 ft apart in the area over the opening, and 1/2 ft from the bottom was specified. Eighteen inches of class A concrete were poured. A 4-in pipe was set into the center of each grid to serve as a marker for future evaluation of the project. The material requirements for each poured slab are shown in table 2.

TABLE 2. - Material requirements per slab

Size of shaft.............ft..	4.5×4.5
Dimension of slab.........ft..	15×15×1.5
Number of No. 7 rebars........	46
Total length of rebars....ft..	690
Total weight of rebars....lb..	1,420
Thickness of concrete.....ft..	1.5
Volume of concrete.......yd^3..	12.5

These slabs were of sufficient size and sufficiently reinforced to remain indefinitely without breaking or flipping over in the event of washout under part of the cap. They were also designed to withstand loads from automobile or truck traffic which may occur in the area following closure of the shafts.

DISCUSSION

Working around abandoned mine shafts in areas where the extent of the abandoned underground mine working and the stability of the surface material around the shafts is not known is potentially hazardous. The contractor and suppliers were aware of the possible hazards and proceeded with due caution and regard for personal safety.

A minimum of installation problems were involved, and only a few changes were necessary in completing the planned demonstration program.

Most of the material trimmed from the shaft openings was allowed to fall into the open shafts, since sufficient waste rock was available on the nearby surface to backfill the openings over the installed plugs. In at least one instance, temporary bridging of a shaft occurred during the trimming operation. This was to be expected because the material was ungraded, but it pointed out the necessity for using graded material when closing small shafts by backfilling.

In preparing hole 14 for plug installation, the hole was found to be larger than original surface measurement had indicated, and it was difficult to obtain a stable bedrock surface. It became apparent that the alternatives were a plug at least 16 ft in diameter, a cap 22 ft in diameter, or completely backfilling the hole; backfilling was chosen, and approximately 350 yd^3 of backfill were required to close the opening. A 4-in pipe was also used as a marker for this closure.

It also became obvious that the shaft dimension measurements made from the surface in these old hand-dug shafts before they were prepared for plugging were not the most reliable measurements that could be made. In several instances, measurements made after the holes were prepared required changes in plug size from original specifications. For example, the plug put in open shaft 19 was the plug meant to be placed in shaft 14.

The original specification required that cross-reinforcing bars be welded near the top of each form to be used for attaching cables for moving the forms. The fabricator preferred to weld a plate with an eye in each corner. Figure 10 shows this to be a preferable method and allowed for easy handling and positioning of the forms. The crossbars in the original design were omitted in the later-constructed forms.

The reinforcing rods were welded into position at crosspoints, and the ends were welded to the sides of the forms. This tended to make very rigid form. The welding of the reinforcing rod ends at the center of the sides was omitted in several of the forms installed near the end of the demonstration. This enabled the form to bow out when filled with concrete to more nearly take the shape of the opening. However, when this happens, there are no reinforcing bars in the bowed-out part of the plug. A modified design that allowed the center reinforcing bars to extend through the plug walls might eliminate this problem.

Four plug forms were set in their respective shafts prior to a 7-in rainfall. As a result, the forms were filled with water and had to be pumped out before the concrete was poured. Small drain holes were left in the last three plugs installed; however, the plugs were filled with concrete before the next rain.

CONCLUSIONS

The 11 plugs and 2 caps installed and the shaft that was backfilled appear to be effective methods for closure in the Galena area. Long-range evaluation of the closures will be necessary to prove the stability of the inverted pyramid plugs.

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